Characterization of the $\alpha \leftrightarrow \beta$ transformations in a Ti–6Al–2Sn–4Zr–6Mo (wt.%) alloy

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Abstract

A Ti–6Al–2Sn–4Zr–6Mo (wt.%) alloy has been subjected to different thermal treatments of solution and aging leading to different amounts and distribution of untransformed α-phase, β-phase and martensite. In order to study the α-phase transformation, and thus to evaluate its kinetic behaviour, its characteristics and its influence in subsequent transformations, dilatometric analysis tests, metallographic studies, hardness, and conductivity measurements have been performed.

Keywords: Titanium alloys; Transformation; Heat treating; Dilatometry; Electrical conductivity

1. Introduction

Like other $\alpha + \beta$ type titanium alloys, Ti–6Al–2Sn–4Zr–6Mo (wt.%) can be subjected to different thermal treatments of solution and aging leading to different amounts and distributions of untransformed α-phase, β-phase and martensite. An understanding of the kinetics of the $\alpha \leftrightarrow \beta$ transformation in the solution treatment allows different thermal treatments to be performed according to the expected amount of untransformed α-phase. During quenching from solution temperatures, the β-phase can transform partially into martensite. Its amount and composition depends on the amount of untransformed α-phase. Dilatometric analysis tests, as well as metallographic studies, have been carried out on samples in the solution and aged condition in order to analyze the α-phase transformation and, thus, to evaluate its kinetic behaviour, its characteristics and its influence in subsequent transformations. To determine the effect of the solution temperature on microstructure and mechanical properties, measurements of electric conductivity and hardness were carried out. The measurements of conductivity as well as the dilatometric analysis demonstrate to be adequate methods to assess the transformation as in similar alloys previously studied

2. Experimental procedure

2.1. Material

Samples were obtained from a Ti–6Al–2Sn–4Zr–6Mo bar of 63 mm diameter. It has been supplied in a rolled and subsequent mill annealing (MA) condition.

2.2. Metallographic study

Different samples were subjected to solution treatments (ST) and heated for 1 h at temperatures between 1075 K and 1250 K with subsequent water quenching. Samples were mechanically polished and electropolished Afterwards, several micrographs were taken to identify all microconstituents and to evaluate the amount of untransformed α-phase, β-phase and martensite. The microstructures found in samples treated at 1075 K, 1100 K and 1125 K were analogous to the non-treated ones. Besides, it will be shown that they all contain a similar α-phase fraction of about 75%. From this metallographic study, we can therefore surmise that transformation of α-phase begins at around 1125 K, and ends (β-*transus*) at around 1225 K. Similar results for the β-*transus* have been reported by other authors

No martensite can be obtained by quenching samples treated below 1175 K, when only metastable β (retained β) is obtained. Above 1175 K it is possible to distinguish the martensite laths and crossed needles situated where α-phase grains

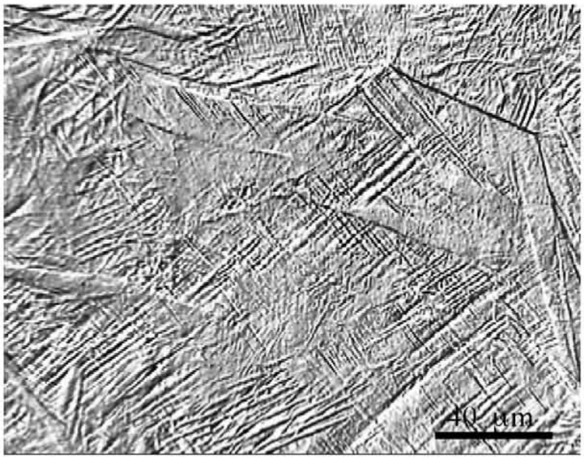

Fig. 1. Ti–6Al–2Sn–4Zr–6Mo alloy: microstructure after solutioning at 1275 K after quench in water and subsequent liquid nitrogen treatment.

were before. For a better observation of the martensite needles, a sub-zero treatment was performed by quenching in water from 1275 K and subsequent cooling in liquid nitrogen (Fig. 1). Different phases in the structure can be much more clearly seen when the aged samples are observed. These were treated at 865 K for 7 h and cooled in air. During the last treatment on electropolished samples, oxidation of the polished surface takes place leading to a better observation of the martensite after aging ("STA") as Fig. 2(a) and (b) shows. Determination of the amount of martensite is not easy, but the results seem to reveal that the quantity of martensite obtained is larger for the sub-zero treatment than the quantity of martensite for the samples cooled to room temperature (solution temperature above the β-*transus*).

2.3. Dilatometric analysis

Tests were made using cylindrical samples 20 mm length and 7.5 mm diameter, which were heated at 10 K/min up to 1325 K and then cooled at the same rate. Fig. 3 shows the thermogram obtained from the first heating–cooling cycle of the dilatometric measurements. In this first heating–cooling cycle, an increase in relative length between 1125 K and 1225 K associated with the $\alpha \leftrightarrow \beta$ transformation is observed. This curve is used for the quantitative evaluations of the transformation

2.4. Electrical conductivity

Electrical conductivity as a function of the solution temperature for samples after ST and STA treatments is shown in Fig. 4. This parameter practically does not change with solution treatment temperatures in the temperature range were the transformation occurs (1125–1225 K). The small changes below 1125 K could be associated with the alloy recovery and/or the recrystallization process prior to the beginning of the transformation.

These results demonstrate that the electrical conductivity measurements taken after ST are not a suitable method to control the structure transformation and the amount of primary α-phase

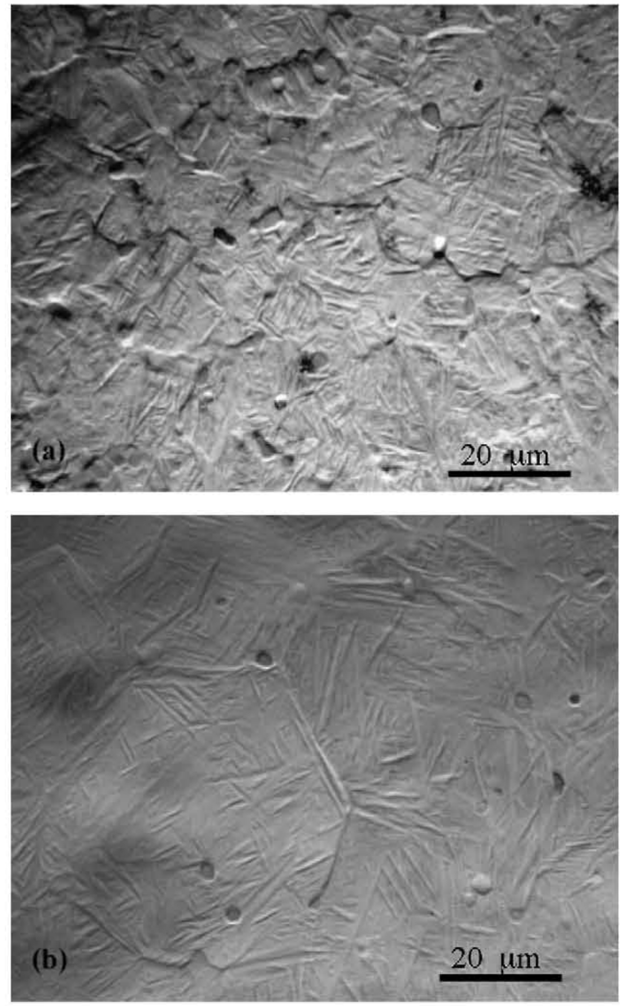

Fig. 2. Ti–6Al–2Sn–4Zr–6Mo alloy: microstructure for different solution temperatures, STA condition: (a) 1200 K STA and (b) 1210 K STA.

or β-phase obtained in heating in this alloy, as well as in other titanium alloys However, in other titanium alloys such as near-β type, these electrical conductivity measurements could be used to control the structure transformations

The results after the STA treatment show that electrical conductivity is practically constant.

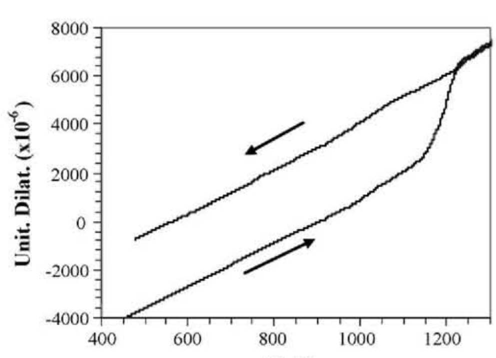

Fig. 3. Dilatometric analysis: Ti–6Al–2Sn–4Zr–6Mo longitudinal sample, first heating.

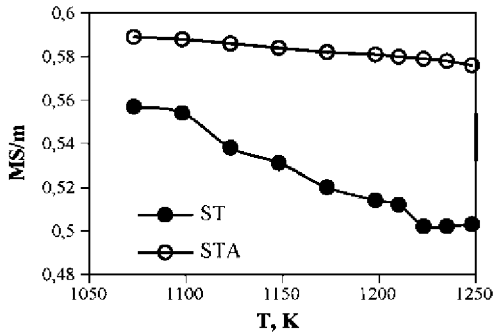

Fig. 4. Ti–6Al–2Sn–4Zr–6Mo electrical conductivity vs. temperature.

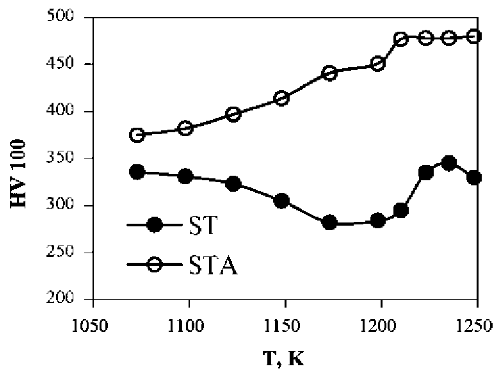

Fig. 5. Ti–6Al–2Sn–4Zr–6Mo hardness vs. solution temperature for ST and STA.

2.5. *Mechanical properties*

Hardness measurements as a function of the solution temperature for aged and non-aged samples are shown in Fig. 5. As it can be seen, a ST does not lead to an increase in the hardness unlike in the case of other titanium alloys This figure also shows how the hardness slightly decreases up to about 1125 K, the temperature for the beginning of the transformation, probably due to a recrystallization process. Above this point, hardness continues diminishing due to the fact that metastable β-phase forms as the temperature increases. For solution temperatures above 1150 K, the hardness increases with increasing temperature because major amounts of martensite are formed. Finally, once the structural transformation is completed around 1225 K, the hardness remains nearly constant.

For STA treatment, the hardness increases with increasing solution temperature, up to the β-*transus*, above which no further changes occur due to the different behaviour during the aging process of martensite and the metastable β-phase.

3. Untransformed α-phase evaluation

Fig. 6 shows the $\alpha \leftrightarrow \beta$ transformation as a function of solution temperature obtained from dilatometric analysis and metallography. The results obtained by the two methods agree excellently. Both show a rapid structural transformation relative to the transformation occurring in other titanium alloys with less

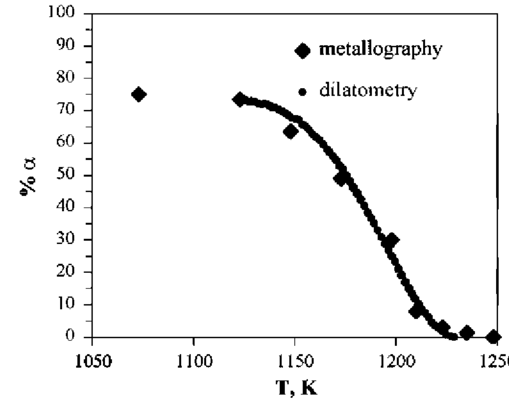

Fig. 6. Primary α (not transformed) percentage vs. solution temperature.

beta stabilizers and with a β-*transus* temperature situated around 1225 K. At the beginning, the transformation is slower, but when a 20% α-phase amount has changed to β, up to the end of the process, the transformation becomes faster and advances at a nearly constant rate.

4. Conclusions

Dilatometric analysis is a quick evaluation method for the $\alpha \leftrightarrow \beta$ transformation in this alloy.

Hardness measurements after ST and STA show that the transformations occurring during the solution treatments are only partial. For this reason, they are not a reliable method to control structural transformations.

Finally, electrical conductivity measurements are easy, fast and non-destructive, making such measurements suitable to study the effect of heat treatment Unfortunately, they are not, in this alloy, a suitable method to control the structure transformation and the amount of primary α-phase or β-phase obtained in heating.

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